EXHIBIT "A"

Wikipedia Article on Strangelets and LHC Strangelet Searches

Strangelet

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A **strangelet** is a hypothetical object consisting of a bound state of roughly equal numbers of up, down, and strange quarks. The size could be anything from a few femtometers across (with the mass of a light nucleus) to something much larger. Once the size becomes macroscopic (on the order of meters across), such an object is usually called a quark star or "strange star" rather than a strangelet. An equivalent description is that a strangelet is a small fragment of strange matter. The term "strangelet" originates with E. Farhi and R. Jaffe.[1] Strangelets have been suggested as a dark matter candidate.

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The main question about strangelets concerns their stability. The known particles with strange quarks are unstable because the strange quark is heavier than the up and down quarks, so strange particles, such as the Lambda particle, which contains an up, down, and strange quark, always lose their strangeness, by decaying via the weak interaction to lighter particles containing only up and down quarks. But states with a larger number of

quarks might not suffer from this instability. This is the "strange matter hypothesis" of Bodmer [2] and Witten.[3] According to this hypothesis, when a large enough number of quarks are collected together, the lowest energy state is one which has roughly equal numbers of up, down, and strange quarks, namely a strangelet. This stability would occur because of the Pauli exclusion principle; having three types of quarks, rather than two as in normal nuclear matter, allows more quarks to be placed in lower energy levels.

[edit] Relationship with nuclei

A nucleus is a collection of a large number of up and down quarks, confined into triplets (neutrons and protons). According to the strange matter hypothesis, strangelets are more stable than nuclei, so nuclei are expected to decay into strangelets. But this process may be extremely slow because there is a large energy barrier to overcome: as the weak interaction starts making a nucleus into a strangelet, the first few strange quarks form strange baryons, such as the Lambda, which are heavy. Only if many conversions occur almost simultaneously will the number of strange quarks reach the critical proportion required to achieve a lower energy state. This is very unlikely to happen, so even if the strange matter hypothesis were correct, nuclei would never be seen to decay to strangelets because their lifetime would be longer than the age of the universe.

[edit] Size

The stability of strangelets depends on their size. This is because of (a) surface tension at the interface between quark matter and vacuum (which affects small strangelets more than big ones), and (b) screening of charges, which allows small strangelets to be charged, with a neutralizing cloud of electrons/positrons around them, but requires large strangelets, like any large piece of matter, to be electrically neutral in their interior. The charge screening distance tends to be of order a few femtometers, so only the outer few femtometers of a strangelet can carry charge [4].

The surface tension of strange matter is unknown. If it is smaller than a critical value (a few MeV per square femtometer [5]) then large strangelets are unstable and will tend to fission into smaller strangelets (strange stars are still stabilized, by gravity). If it is larger than the critical value, then strangelets become more stable as they get bigger.

[edit] Natural or artificial occurrence

Although nuclei do not decay to strangelets, there are other ways to create strangelets, so if the strange matter hypothesis is correct there should be strangelets in the universe. There are at least three ways they might be created in nature:

- Cosmogonically, i.e., in the early universe when the QCD confinement phase transition occurred. It is possible that strangelets were created along with the neutrons and protons which form ordinary matter.
- High energy processes. The universe is full of very high-energy particles (cosmic rays). It is possible that when these collide with each other or with neutron stars

they may provide enough energy to overcome the energy barrier and create strangelets from nuclear matter.

- Cosmic ray impacts. In addition to head-on collisions of cosmic rays, ultra high energy cosmic rays impacting Earth's atmosphere may create strangelets.

These scenarios offer possibilities for observing strangelets. If there are strangelets flying around the universe, then occasionally a strangelet should hit Earth, where it would appear as an exotic type of cosmic ray. If strangelets can be produced in high energy collisions, then we might make them at heavy-ion colliders.

[edit] Accelerator production

At heavy ion accelerators like RHIC, nuclei are collided at relativistic speeds, creating strange and antistrange quarks which could conceivably lead to strangelet production. The experimental signature of a strangelet would be its very high ratio of mass to charge, which would cause its trajectory in a magnetic field to be extremely straight. The STAR collaboration has searched for strangelets produced at the Relativistic Heavy Ion Collider,[6] but none were found. It is believed that the higher energy of the lead-lead collisions of the Large Hadron Collider (LHC), compared to the RHIC, will produce more strange quarks in the quark-gluon plasma (QGP) than are produced at RHIC's QGP. This higher production of strange quarks might allow for production of a strangelet at the LHC, and searches[7] are planned for such upon commencement of collisions at the LHC ALICE detector.

[edit] Space-based detection

The Alpha Magnetic Spectrometer (AMS), an instrument which is planned to be mounted on the International Space Station, could detect strangelets [8].

[edit] Possible seismic detection

In May 2002, a group of researchers at Southern Methodist University reported the possibility that strangelets may have been responsible for a seismic event recorded on October 22 and November 24 in 1993 [9]. The authors later retracted their claim, after finding that the clock of one of the seismic stations had a large error during the relevant period.[10]

It has been suggested that the International Monitoring System being set up to verify the Comprehensive Nuclear Test Ban Treaty (CTBT) may be useful as a sort of "strangelet observatory" using the entire Earth as its detector. The IMS will be designed to detect anomalous seismic disturbances down to 1 kiloton of TNT's equivalent energy release or less, and could be able to track strangelets passing through Earth in real time if properly exploited.

[edit] Dangers

If the strange matter hypothesis is correct and a strangelet comes in contact with a lump of ordinary matter such as Earth, it could convert the ordinary matter to strange matter. This "ice-nine" disaster scenario is as follows: one strangelet hits a nucleus, catalyzing its immediate conversion to strange matter. This liberates energy, producing a larger, more stable strangelet, which in turn hits another nucleus, catalyzing its conversion to strange matter. In the end, all the nuclei of all the atoms of Earth are converted, and Earth is reduced to a hot, large lump of strange matter.

This is not a concern for strangelets in cosmic rays because they are produced far from Earth and have had time to decay to their ground state, which is predicted by most models to be positively charged, so they are electrostatically repelled by nuclei, and would rarely merge with them [11][12]. But high-energy collisions could produce negatively charged strangelet states which live long enough to interact with the nuclei of ordinary matter [13].

The danger of catalyzed conversion by strangelets produced in heavy-ion colliders has received some media attention,[14][15] and concerns of this type were raised [16][17] at the commencement of the Relativistic Heavy Ion Collider (RHIC) experiment at Brookhaven, which could potentially have created strangelets. A detailed analysis [18] concluded that the RHIC collisions were comparable to ones which naturally occur as cosmic rays traverse the solar system, so we would already have seen such a disaster if it were possible. RHIC has been operating since 2000 without incident. Similar concerns have been raised about the operation of the Large Hadron Collider (LHC) at CERN [19] but such fears are dismissed as far-fetched by many scientists [19][20] [21].

In the case of a neutron star, the conversion scenario seems much more plausible. A neutron star is in a sense a giant nucleus (20 km across), held together by gravity, but it is electrically neutral and so does not electrostatically repel strangelets. If a strangelet hit a neutron star, it could convert a small region of it, and that region would grow to consume the entire star, creating a quark star.[22]

It should be remembered all the issues discussed above relating to the conversion of ordinary matter to strange matter only arise if the strange matter hypothesis is true, *and* its surface tension is larger than the afore-mentioned critical value.

[edit] Debate about the strange matter hypothesis

The strange matter hypothesis remains unproven. No direct search for strangelets in cosmic rays or particle accelerators has seen a strangelet (see references in earlier sections). If any of the objects we call neutron stars could be shown to have a surface made of strange matter, this would indicate that strange matter is stable at zero pressure, which would vindicate the strange matter hypothesis. But there is no strong evidence for strange matter surfaces on neutron stars (see below).

Another argument against the hypothesis is that if it were true, all neutron stars should be made of strange matter, and otherwise none should be.[23] Even if there were only a few

strange stars initially, violent events such as collisions would soon create many strangelets flying around the universe. Because one strangelet will convert a neutron star to strange matter, by now all neutron stars would have been converted. This argument is still debated,[24][25][26][27] but if it is correct then showing that one neutron star has a conventional nuclear matter crust would disprove the strange matter hypothesis.

Because of its importance for the strange matter hypothesis, there is an ongoing effort to determine whether the surfaces of neutron stars are made of strange matter or nuclear matter. The evidence currently favors nuclear matter. This comes from the phenomenology of X-ray bursts, which is well-explained in terms of a nuclear matter crust,[28] and from measurement of seismic vibrations in magnetars.[29]

[edit] In fiction

An episode of *Odyssey 5* featured an attempt to destroy the planet by intentionally creating strangelets in a particle accelerator.

The BBC docudrama *End Day* features a scenario where a particle accelerator in New York City explodes, starting a catastrophic chain reaction which destroys Earth.

[edit] References

1. ^ E. Farhi and R. Jaffe, "Strange Matter", Phys. Rev. D30, 2379 (1984)
2. ^ A. Bodmer "Collapsed Nuclei" Phys. Rev. D4, 1601 (1971)
3. ^ E. Witten, "Cosmic Separation Of Phases" Phys. Rev. D30, 272 (1984)
4. ^ H. Heiselberg, "Screening in quark droplets", Phys. Rev. D48, 1418 (1993)
5. ^ M. Alford, K. Rajagopal, S. Reddy, A. Steiner, "The Stability of Strange Star Crusts and Strangelets", Phys. Rev. D73 114016 (2006) arXiv:hep-ph/0604134
6. ^ STAR Collaboration, "Strangelet search at RHIC", arXiv:nucl-ex/0511047
7. ^ A. Angelis et al., "Model of Centauro and strangelet production in heavy ion collisions", Phys. Atom. Nucl. 67:396-405 (2004) arXiv:nucl-th/0301003
8. ^ J. Sandweiss, "Overview of strangelet searches and Alpha Magnetic Spectrometer: When will we stop searching?" J. Phys. G30:S51-S59 (2004)
9. ^ D. Anderson et al, "Two seismic events with the properties for the passage of strange quark matter through the earth" arXiv:astro-ph/0205089
10. ^ E.T. Herrin et al, "Seismic Search for Strange Quark Nuggets" [1]
11. ^ J. Madsen, "Intermediate mass strangelets are positively charged", Phys. Rev. Lett. 85 (2000) 4687-4690 (2000) arXiv:hep-ph/0008217
12. ^ J. Madsen "Strangelets in Cosmic Rays", for Proceedings of 11th Marcel Grossmann Meeting, Germany, Jul 2006, arXiv:astro-ph/0612784
13. ^ J. Schaffner-Bielich, C. Greiner, A. Diener, H. Stoecker, "Detectability of strange matter in heavy ion experiments", Phys. Rev. C55:3038-3046 (1997), arXiv:nucl-th/9611052
14. ^ New Scientist, 28 August 1999: "A Black Hole Ate My Planet" [2]
15. ^ *Horizon: End Days*, an episode of the BBC television series *Horizon*

16. ^ W. Wagner, "Black holes at Brookhaven?" and reply by F. Wilzcek, Letters to the Editor, Scientific American July 1999
17. ^ A. Dar, A. De Rujula, U. Heinz, "Will relativistic heavy ion colliders destroy our planet?", Phys. Lett. B470:142-148 (1999) arXiv:hep-ph/9910471
18. ^ W. Busza, R. Jaffe, J. Sandweiss, F. Wilczek, "Review of speculative 'disaster scenarios' at RHIC", Rev. Mod. Phys.72:1125-1140 (2000) arXiv:hep-ph/9910333
19. ^ a b Dennis Overbye, Asking a Judge to Save the World, and Maybe a Whole Lot More, NY Times, 29 March 2008 [3]
20. ^ "Safety at the LHC".
21. ^ J. Blaizot et al, "Study of Potentially Dangerous Events During Heavy-Ion Collisions at the LHC", CERN library record CERN Yellow Reports Server (PDF)
22. ^ C. Alcock, E. Farhi and A. Olinto, "Strange stars", Astrophys. Journal 310, 261 (1986)
23. ^ J. Friedman and R. Caldwell, "Evidence against a strange ground state for baryons", Phys. Lett. B264, 143-148 (1991)
24. ^ J. Madsen, "Strangelets as cosmic rays beyond the GZK-cutoff", Phys. Rev. Lett. 90:121102 (2003) arXiv:stro-ph/0211597
25. ^ S. Balberg, "Comment on 'strangelets as cosmic rays beyond the Greisen-Zatsepin-Kuzmin cutoff'", Phys. Rev. Lett. 92:119001 (2004), arXiv:astro-ph/0403503
26. ^ J. Madsen, "Reply to Comment on Strangelets as Cosmic Rays beyond the Greisen-Zatsepin-Kuzmin Cutoff", Phys. Rev.Lett. 92:119002 (2004), arXiv:astro-ph/0403515
27. ^ J. Madsen, "Strangelet propagation and cosmic ray flux",Phys. Rev. D71, 014026 (2005) arXiv:astro-ph/0411538
28. ^ A. Heger, A. Cumming, D. Galloway, S. Woosley, "Models of Type I X-ray Bursts from GS 1826-24: A Probe of rp-Process Hydrogen Burning", arXiv:0711.1195
29. ^ A. Watts and S. Reddy, "Magnetar oscillations pose challenges for strange stars", MNRAS, 379, L63 (2007) arXiv:astro-ph/0609364

[edit] External links and further reading

- The Story of Strangelets
- F. Weber, "Strange quark matter and compact stars", Prog. Part. Nucl. Phys. 54:193-288 (2005) arXiv:astro-ph/0407155
- J. Madsen, "Physics and Astrophysics of Strange Quark Matter" Lect. Notes Phys. 516 162-203 (1999) arXiv:astro-ph/9809032

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